Optimal Fascicle Length Changes Based on Submaximal Force or Activation

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Introduction

- de Brito Fontana and Herzog (2016) described the submaximal force-length relationship of the vastus lateralis muscle obtained using force and muscle activation criteria **[1]**.
  - *Muscle force criteria*, optimal fascicle length shifts towards longer lengths with respect to the maximal force condition.
  - *Muscle activation criteria,* optimal fascicle length did not shift from the maximal activation condition.
- Since the vastus lateralis is one of a four muscle system that extends the knee, the knee joint torque may not directly relate to the vastus lateralis activation and fascicle lengths.
- The first dorsal interosseous muscle (FDI) is the only muscle that acts to abduct the second metacarpophalangeal joint and the force length curve of the FDI has been measured in vivo **[2]**.
- **Purpose:** To investigate the phenomena described by de Brito Fontana and Herzog in the FDI.

Materials and Methods

- **Subjects**
  - Nine subjects, seven male and two female
  - Mean age: 24.3±5.2 years, mean height: 176.2±2.1 cm, mean mass: 80.7±40.1 kg, mean hand length: 18.9±0..5 cm
- **Protocol**
  - The right FDI of each subject was tested. (Hand Dominance: eight right and one left) **(Figure 1)**
  - A wireless EMG electrode (Trigno mini sensor, Delsys, Natic, MA) was placed over the second metacarpal head of the FDI. Ultrasound videos were collected using a 10 MHz ultrasound probe (EchoBlaster 128, Telemed, Lithuania).
  - A standoff pad was used in conjunction with the ultrasound probe head to produce a clear image and to avoid letting ultrasound gel touch the EMG electrode.
  - The subject placed their hand in a custom made apparatus which only allowed the second metacarpophalangeal joint to move.
  - The second finger pressed against a force sensor which was fixed at known joint angles (0º, 5º, 10º, 15º, 20º).
  - The subject was instructed to contract from rest to maximal force in a 3 second interval while producing a steady force increase.
  - The force applied to the sensor, the muscle activity of the FDI, and an ultrasound video of the muscle fascicles were recorded for two contractions at each joint angle. The contraction that produced the highest absolute force was analyzed. **(Figure 2)**

Data Analysis

- Data were analyzed using custom written Matlab code based on the method described by de Brito Fontana and Herzog [1]. Force and activation data were filtered then normalized to the maximum respective value for each joint angle. Submaximal data points for 20%, 40%, 60%, 80%, and 100% of maximal force and activation for reach joint angle were located. At these points, the corresponding frame from the ultrasound video was manually digitized to determine fascicle length.

Figure 1. Custom made apparatus, wireless EMG electrode, ultrasound probe, standoff gel pad, and force sensor was used to for data collection protocol.

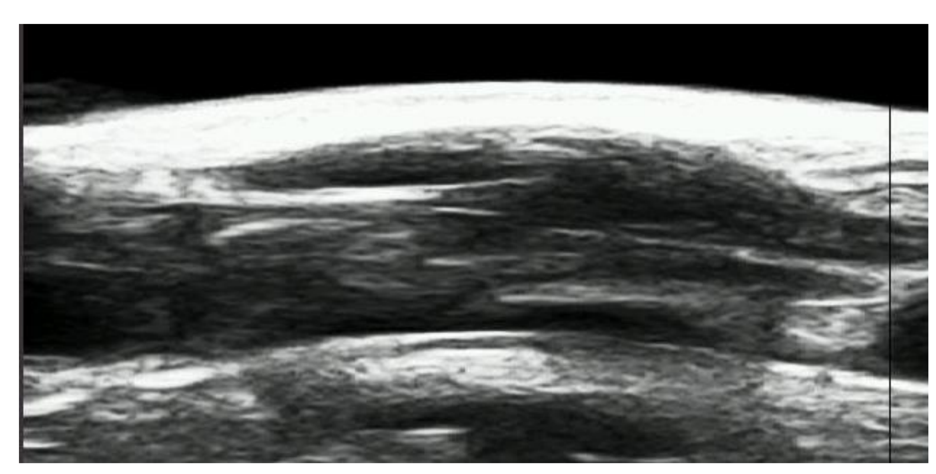

Figure 2. The corresponding frame from the ultrasound video was manually digitized to determine fascicle length assuming the angle formed by the deep and superficial aponeurosis of the distal muscle belly was representative of fascicle pennation angle. **[3].**

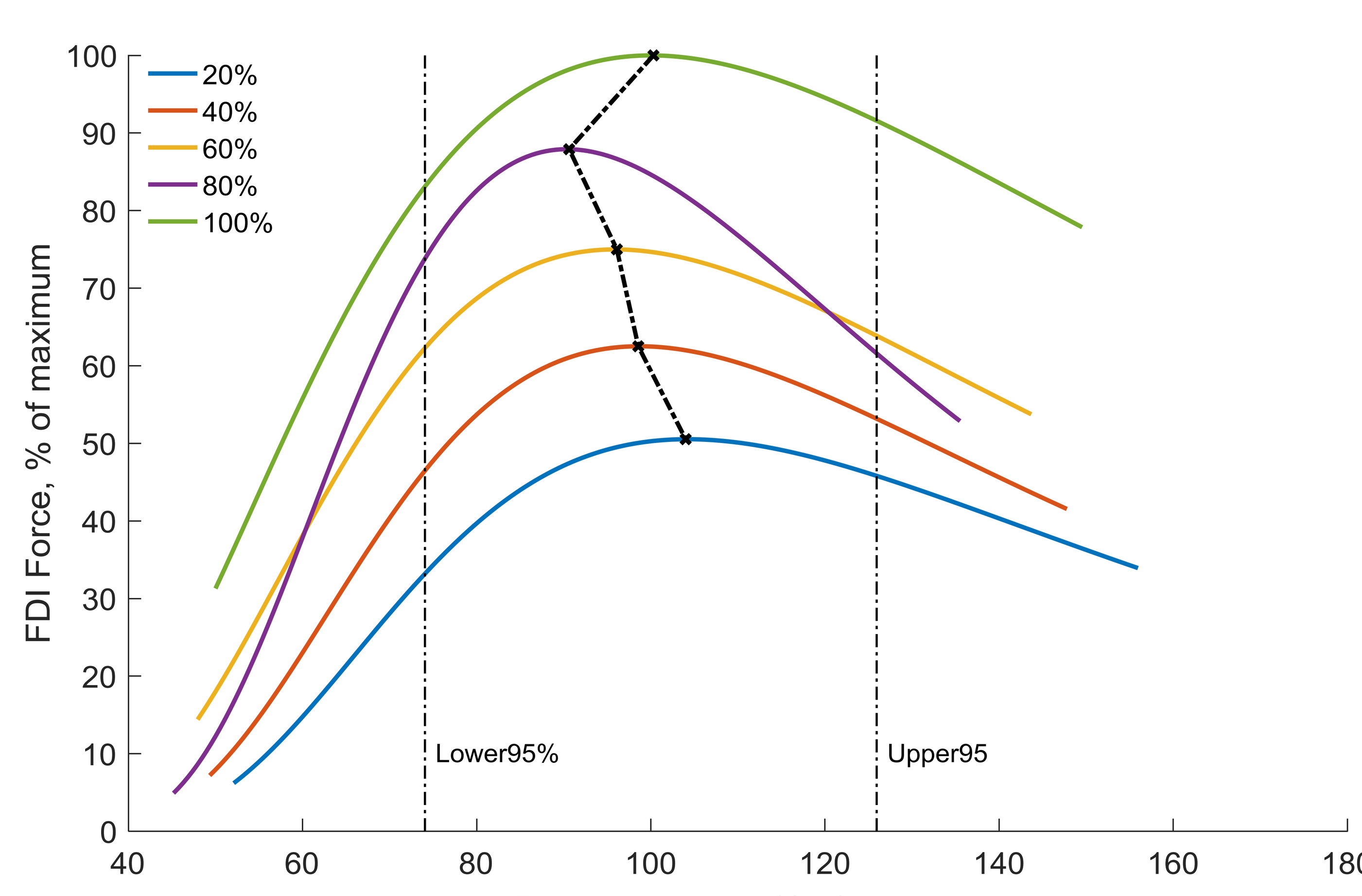

Figure 3. Muscle force length curves based on percent of maximal force.

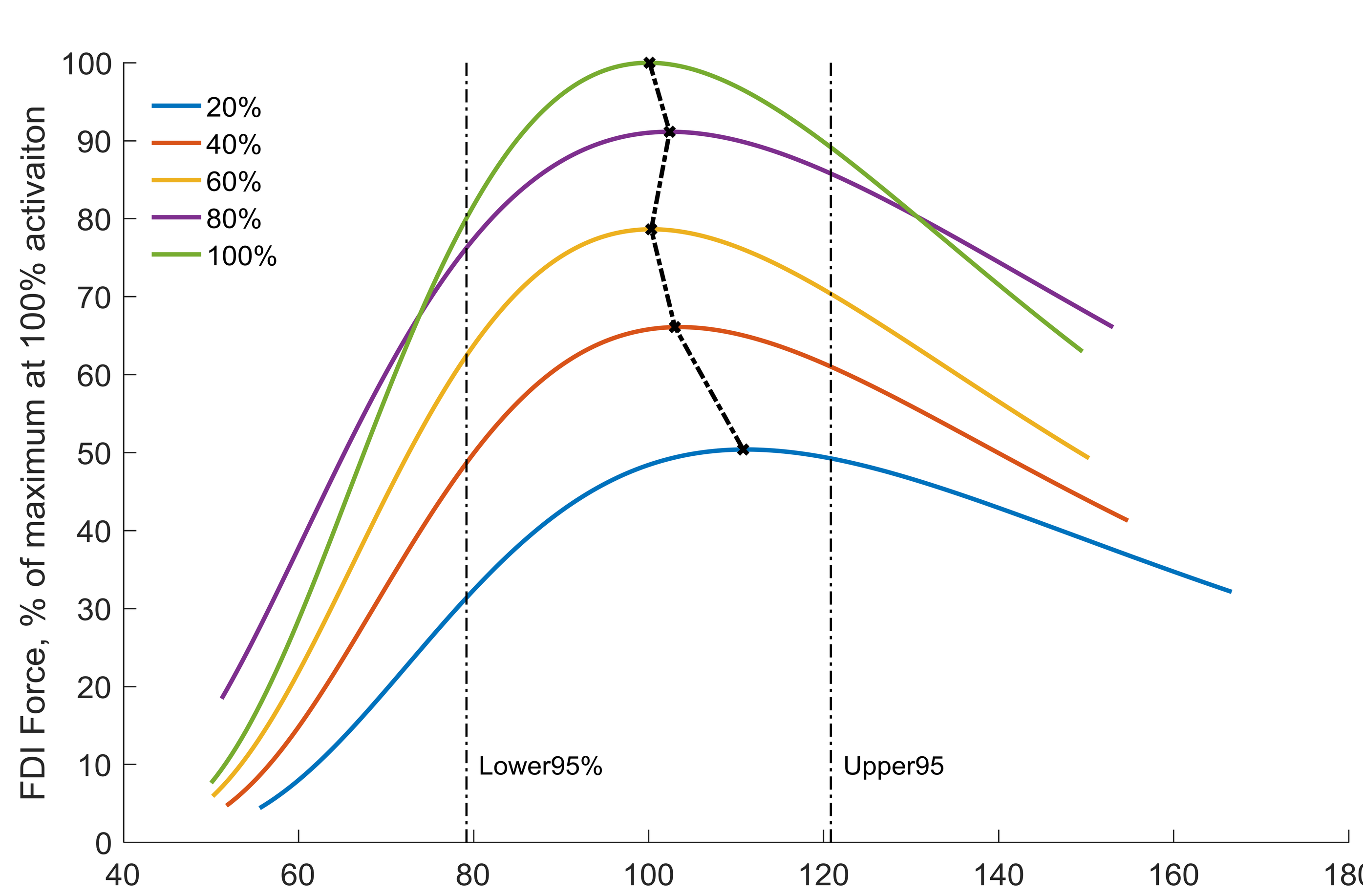

Figure 4. Muscle force length curves based on percent of maximal activation.

Data Analysis cont.

- Fascicle length and force data were normalized by the respective maximum values for each subject across joint angles and contraction levels. Subject data were averaged together then the average data were fit to a force-length curve using a least squares method with the following equation:

$$F_L(L_F) = 1 - \left(\frac{(L_F - L_{F,OPT})}{w.L_{F,OPT}} \right)^2$$

- Where LF is the range of fascicle lengths, LF,OPT is the optimal fascicle length, and w indicates the width of the force length curve.

Results and Discussion

- Results of the repeated measures ANOVA, on 20%, 40%, 60%, 80%, and 100% maximum force and activation concluded that there is no significant main effect for optimum fascicle length ($p < 0.05$).
- Figures 3 and 4 show similar fascicle length trends with decreasing percentages of maximum force and activation. This is contrary to that of de Brito Fontana and Herzog (2016), where optimal fascicle length for submaximal conditions varied depending on the submaximal criteria. The large 95% confidence intervals could be explained by the physical size of muscle investigated.
- Single muscle systems such as the FDI provide a more mathematically determinate system for muscle force estimation, thus eliminating some assumptions, but they produce alternative challenges that must be addressed.

Limitations

- Limitations with this study include a small sample size, the small range of motion of the FDI, and the difficulty in manually digitizing the FDI pennation angle.
  - Small sample size was due in part to the high protocol specificity and sensitivity of data collection; seventeen subjects participated in this study but ten data sets required rejection.
  - The small range of motion of the FDI made determining the parameters of the force-length difficult since a large range of fascicle lengths could not be directly measured. Using a muscle with a larger range of motion at a joint would help to further clarify the differences in optimal fascicle length based on submaximal measurement criteria.
  - Manual digitization of pennation angle is a time consuming process that is likely influenced by investigator inconsistency and bias. Automated image processing may provide further consistency and analysis of all ultrasound images.

Conclusion

- Considerations for revision may benefit from a single subject design, increasing sample size, implementing automated analysis, or investigating other muscle systems such as the triceps brachii.

References

1. de Brito Fontana H and Herzog W, Eur J Appl Physiol, 116, 1267-1277, 2016
2. Infantolino BW and Challis JH, Ann Biomed Eng 42(6) 1331-1339.
3. Zuurbier C and Huijing P, Journal of Biomechanics, 25(9), 1017-1026, 1992